LA-UR -84-2027

LA-UR--84-2027

DE84 014025

TITLE: UNITARY, UNIFIED MODELS FOR NN → NNπ

AUTHOR(S): Richard R. Silbar, T-5

SUBMITTED TO: For proceedings of the Conference on the Intersections Between Particle and Nuclear Physics, Steamboat Springs, CO, May 23-30, 1984

MASTER

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

UNITARY, UNIFIED MODELS FOR NN → NNπ

Richard R. Silbar
Los Alamos National Laboratory, Los Alamos, New Mexico 87545*

ABSTRACT

First-generation unitary, unified models reproduce the new NN → NNπ data reasonably well, but there are two interesting "warts" in the comparison of theory and experiment.

INTRODUCTION

Since 1958 the usual treatment of single-pion production in nucleon-nucleon collisions has been the isobar model (Fig. 1). In the past ten years there has been a concerted effort by several groups to calculate the "blobs" for the NN → Nα part of the amplitude in a unitary way.

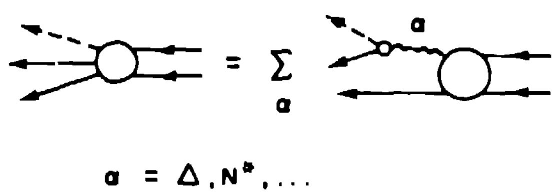

Fig. 1. Isobar model, NN → NNπ

There have been several different approaches. Some groups have employed a coupled two-body channels method.[1,2] Others[3-8] have solved Faddeev-like coupled integral equations, satisfying the constraints of two- and three-body unitarity. Closely related to the latter method is the more phenomenological approach of the Argonne group.[9] Most, but not all, of these groups have been interested in the reactions πd → πd and NN → dπ (which are not discussed in this paper) rather than the two-to-three-body reaction NN → NNπ.

TOTAL INELASTIC CROSS SECTIONS

From the on-shell NN → NN amplitude that is calculated in the different unified models, one can use the optical theorem to obtain total cross sections. Figure 2 shows one of the first attempts[3] to do this for the total spin-averaged I=1 inelastic (NN → NNπ) cross section. The model, having no free parameters, only takes into account (iterated) pion exchange between the nucleons and Δ resonances. The success of the comparison to data contrasts strongly with Born approximation calculations of this cross sec-

---

*Work supported by the U.S. Department of Energy.

tion, which are off in magnitude and/or shape as a function of energy. Note, by the way, that two-pion production, $NN \rightarrow NN\pi\pi$, only becomes important above 1500 MeV. This provides some justification for the use of a three-body approach to NN inelasticity in the medium-energy regime.

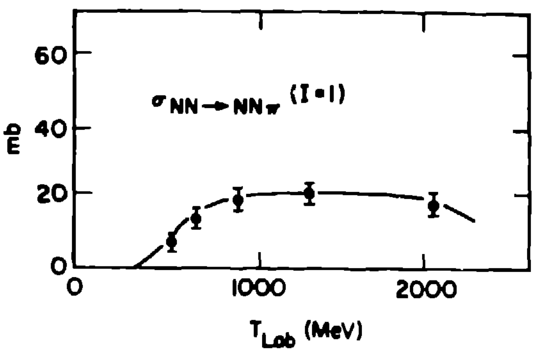

Fig. 2. Spin-averaged I=1

However, the result shown in Fig. 2 is a bit fortuitous. The difference in longitudinally spin-dependent inelastic cross sections, $\Delta\sigma_{L,inel} = \sigma_{inel}(\rightleftarrows) - \sigma_{inel}(\rightrightarrows)$, has been recently found to be[10] very different from the predictions of that model (Fig. 3). Even the <u>shape</u> of the energy dependence is wrong. There are similar mispredictions of this quantity by other (more recent) conventional models.[11] We are forced to conclude that present-day models are missing a great deal of the triplet inelasticity that is actually present.

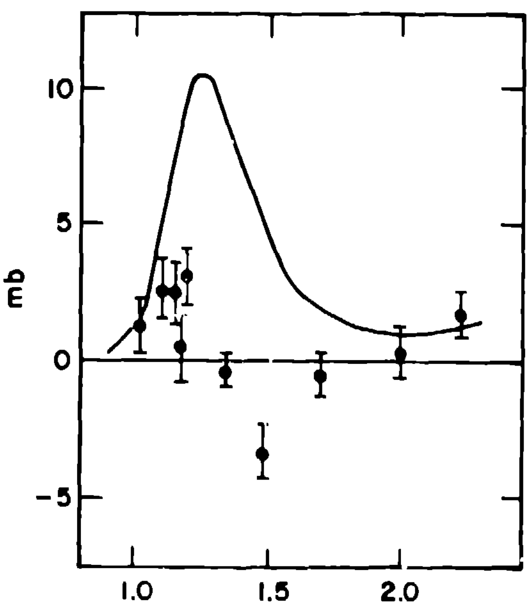

Fig. 3. I=1 $\Delta\sigma_{L,inelas}$.

This is the first interesting wart. It has recently been confirmed in a different way by extracting[12] the separate singlet and triplet inelastic cross sections. Figure 4 shows how much the Kloet-Silbar model (OPE version) overpredicts the singlet and underpredicts the triplet inelasticities. In the other unified models the author is aware of there is a similar tendency to overemphasize the singlet contribution (dominated by the $NN(^1D_2) \rightarrow N\Delta(^5S_2)$ partial wave) and to underestimate the triplet waves. This conclusion can also be drawn from some of the $NN \rightarrow NN\pi$ data now to be discussed.

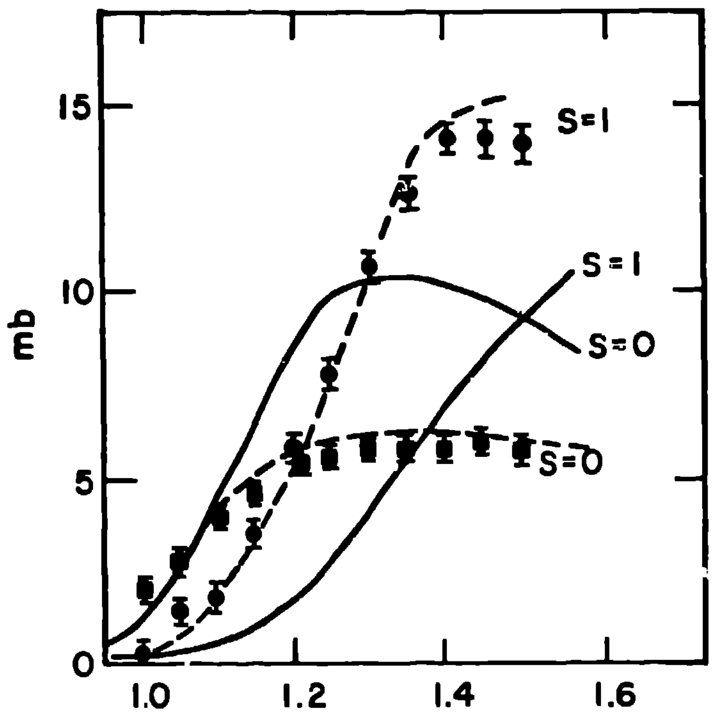

Fig. 4. I=1 singlet and triplet inelastic cross sections.

NN → NNπ -- EXCLUSIVE KINEMATICS

It is only quite recently that we have witnessed an explosion in our knowledge of reactions like pp → npπ$^+$, particularly with respect to its rich spin dependence. For somewhat peculiar technical reasons, Dubach, Kloet, and I have been the only group active in producing unitary model predictions[13] for this two-to-three-body process. This is because our procedure for solving the coupled integral equations (Pade approximants) is well-suited to breakup problems, whereas the contour rotation method used by most other groups solving Faddeev-like equations is better applied to two-to-two reactions, such as pp → dπ. In the same vein, the Helsinki coupled-channels method requires a Fourier transformation to momentum space to be applied to breakup. For this reason, all of the theoretical curves[13] in the figures shown in the rest of this paper use the model of Ref. 3.

Figure 5 shows how this model, with pion-exchange forces only, compares with some differential cross sections[14] for completely determined final state kinematics. As not unexpected for an isobar

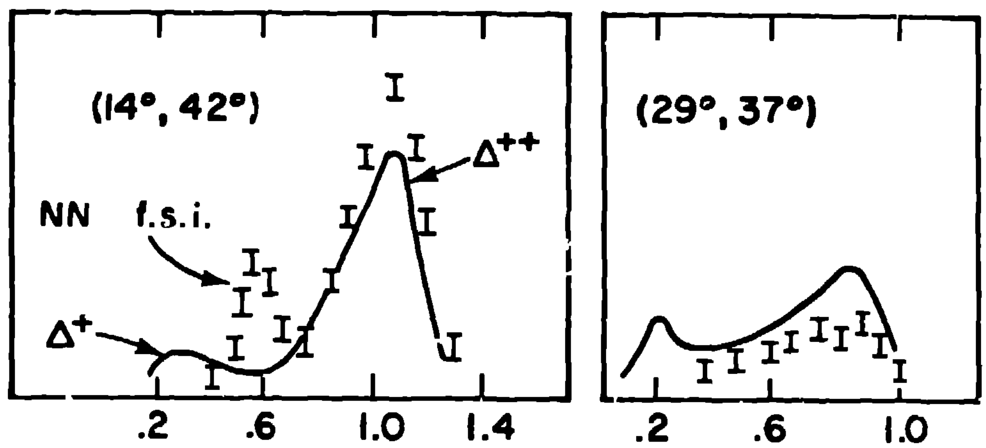

Fig. 5. Cross sections at 800 MeV for $pp \rightarrow np\pi^+$ for two representative angle pairs, versus final proton momentum in GeV/c. Data are from Ref. 14.

model calculation, the peaks representing the Δ resonances are well reproduced. More to the point here, the unitary model does reasonably well in reproducing the magnitudes of these cross sections. It is apparent, however, that the model predictions are somewhat more isotropic than the data. This flatter angular distribution (with respect to the proton angle, say) can be attributed to the excess of inelasticity in the $NN(^1D_2) \rightarrow N\Delta(^5S_2)$ amplitude, as discussed in the last section.

There is also an interesting bump in the $(14^0,42^0)$ momentum distribution near 600 MeV/c, that is not at all reproduced by the model. This peak is due to the s-wave final state interaction between the proton and neutron, their relative energy being nearly zero around this proton momentum. Such an interaction is not included in our three-body model (though we are considering adding such an effect in an approximate way.) It will be interesting to see how this effect alters the spin-dependent observables as well as the cross section.

An observable which is much more sensitive to model details is the beam polarization asymmetry, A_{NO}, in the reaction $\vec{p}p \rightarrow np\pi^+$. This is because such a quantity depends on the relative phase between a spin-flip and a non-flip amplitude. Figure 6 shows a "typical" case, as measured by the Rice-Houston group[14] at 800 MeV. For other angle pairs the agreement between the pion-exchange-only calculations and data is better and worse. Note that the Born approximation prediction (dashed curve) is quite different from that of the unitary model.

It is now possible to also measure spin-spin correlations, A_{ij}, for this reaction using polarized beams and polarized targets. An extensive experiment has been performed by the BASQUE group[15] at TRIUMF for $\vec{p}\vec{p} \rightarrow np\pi^+$ near 500 MeV. The comparison with prediction for several A_{ij} at various angle pairs is shown in Fig. 7. The pion-exchange model does rather well in reproducing these data, though the error bars on the data points are fairly large. Another such observable, not shown, A_{SL}, is not in good agreement with the model predictions. Like the polarizations, A_{SL} is also sensitive to relative phases between amplitudes. An "extended partial wave analysis" of these data is now underway, in which the higher partial wave amplitudes are taken from the pion-exchange model, but the lower-L partial waves (presumably not well-calculated in this model) are fitted. The results of this analysis, I would imagine, will confirm that there is too much singlet inelasticity in the model.

Very recently there have appeared measurements of spin-transfer (Wolfenstein) parameters for this reaction, $\vec{p}p \rightarrow \vec{p}n\pi^+$.[16] Figure 8 shows some of this (preliminary) data and its comparison with the pion-exchange model. Again, it will be interesting to see how including NN final state interactions changes the comparison between theory and experiment.

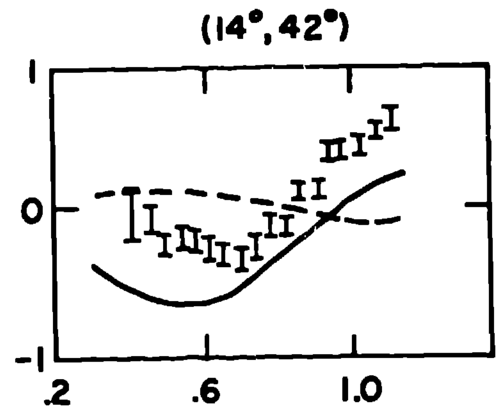

Fig. 6. Polarization A_{N0} for $pp \rightarrow np\pi^+$ at 800 MeV.

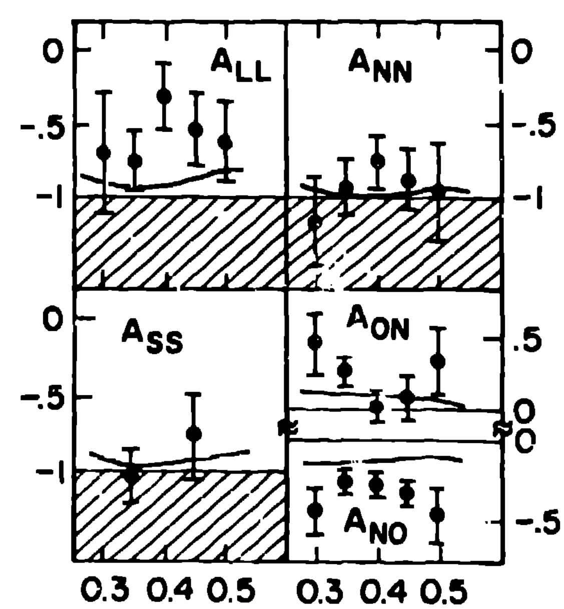

Fig. 7. Spin-spin correlations, $pp \rightarrow np\pi^+$, 500 MeV.

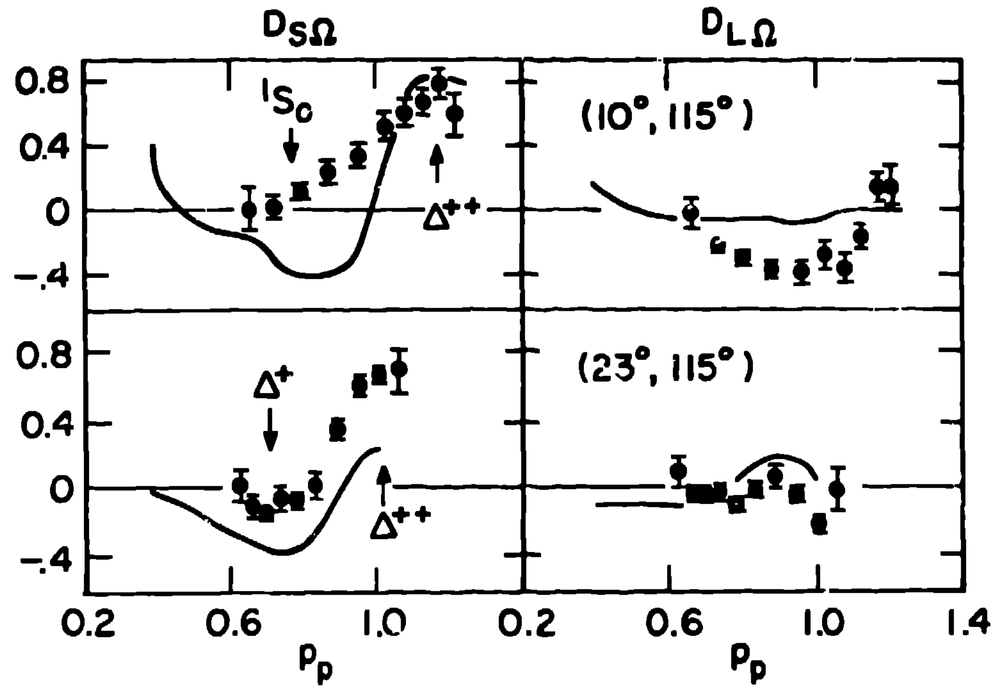

Fig. 8. Spin-transfer coefficients for $pp \rightarrow np\pi^+$ at 800 MeV.

NN → NNπ -- INCLUSIVE KINEMATICS

From the experimental standpoint it is quite a bit easier to do inclusive pion production experiments, detecting only one particle in the final state. Theoretically, the integration over the phase space of the unobserved final particles is sometimes tricky (the integrand is rather peaked) and may wash out some of the interesting dynamical features that can be seen in the exclusive cross sections. Nonetheless, as we shall see, such experiments often provide us with interesting new information (or puzzles).

Figure 9 shows the forward cross sections and beam polarization asymmetry[17] for $\vec{p}p \rightarrow pX$ at 800 MeV. Again, one sees that the data is more forward peaked than the prediction. Also, the unitary prediction of the pion-exchange model is in much better agreement with the data than the Born approximation. Incidentally, the shoulder in the cross section at p_p=0.600 GeV/c is, as above, probably due to a final state interaction between the two nucleons. Again, will the prediction of the asymmetry in this region can be improved by including this interaction in the model?

We now come to the second major wart, which is depicted in Fig. 10. There is a big disagreement between this model and the inclusive spin transfer coefficients K_{NN} and K_{LL} measured[18] in 800 MeV $\vec{p}p \to \vec{n}X$. As it turns out, there is little difference between the unitary model predictions for these quantities and the Born approximation. (Our Born approximation curves here and in Fig. 9 agree very closely with those given earlier by VerWest.[19]) What is the missing piece of physics that could explain the discrepancy? I don't know. For one thing, it is not obvious that it has anything to do with triplet inelasticity.

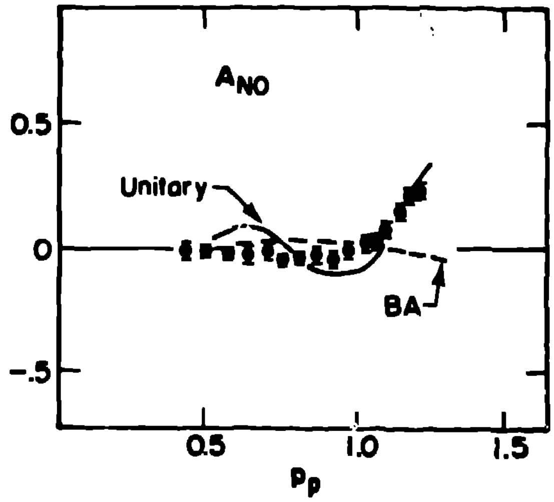

Fig. 9. A_{NO} for pp → pX at 800 MeV.

IMPROVEMENTS AND CONCLUSIONS

What are the future improvements in theoretical models of single pion production in NN collisions that can and should be made? The first, and most obvious, is that the monopoly "enjoyed" by Dubach, Kloet, and Silbar must be broken. Other models must be brought to bear on the burgeoning NN → NNπ data base. Without other model predictions, it is difficult to assess the model dependence exhibited by the different observables.

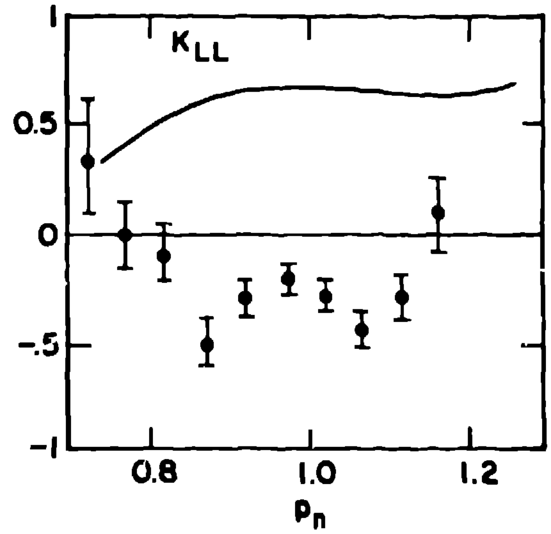

Fig. 10. Spin-transfer K_{LL} for pp → nX at 800 MeV.

Next, it is necessary to go beyond the (iterated) pion exchange calculations presented here. To some extent the more phenomenological approach of Betz and Lee[9] and the Helsinki group[1] does this, but we have as yet no predictions for the NN → NNπ process from these models. It <u>is</u> possible for us to include other forces in the driving terms of our inhomogeneous integral equations. The most straightforward way of doing this is by adding (static) heavy boson exchange graphs (ρ, ω, σ, ...) to our NN → NN′ and NN → NΔ Born terms.

From earlier work on fitting the low-energy NN phases using coupled two-body channels[20] it does appear that ρ-exchange in the NN → NΔ graph will reduce the size of the $^1D_2$ phase shift (the NN → NΔ → NN box diagram provides an attractive force, particularly in this partial wave) and increase the amount of triplet scattering. It remains to be seen whether such an addition is enough to fix up the discrepancy (Wart #1) with the $\Delta\sigma_L$ measurement. With regard to the inclusive K_{LL} discrepancy (Wart #2) one even has some reason to believe (from VerWest's Born approximation calculations[19]) that ρ-exchange is not likely to be the missing ingredient, but that also needs to be established.

To summarize my major conclusions regarding the new model calculations of NN → NNπ observables: (1) On the whole the unified, unitary models do fairly well in explaining the present data. (2) There is a clear need, however, for more triplet inelasticity in today's models. (3) There appears to be a serious problem in understanding the spin transfer coefficients in $\vec{p}p \to \vec{n}X$.

REFERENCES

1. A. M. Green, J. A. Niskanen and M. E. Sainio, J. Phys. G (Nucl. Phys.) 4, 1055 (1978).
2. E. L. Lomon, Phys. Rev. D 26, 576 (1982).
3. W. M. Kloet and R. R. Silbar, Nucl. Phys. A 338, 281 and 317 (1980); A 364, 346 (1981).
4. H. Garcilazo, Phys. Rev. Lett. 45, 780 (1980).
5. A. S. Rinat et al., Nucl. Phys. A 364 486 (1981).
6. C. Fayard, G. H. Lamot and T. Mizutani, Phys. Rev. Lett. 45, 524 (1980).
7. B. Blankleider and I. R. Afnan, Phys. Rev. C 24, 1572 (1981).
8. T. Ueda, Phys. Lett. 119B, 281 (1982).
9. M. Betz and T.-S. H. Lee, Phys. Rev. C 23, 375, (1981); 29, 195 (1984).
10. I. P. Auer et al., Phys. Rev. Lett. 51, 1411 (1983).
11. R. Bhalerao and A. S. Rinat, unpublished; A. Koenig and P. Kroll, Nucl. Phys. A 356,345 (1981).
12. G. Glass, private communication.
13. J. Dubach et al., Phys. Lett. B 106,29 (1981); J. Phys. G (Nucl. Phys.) 8, 475 (1982).
14. A. D. Hancock et al., Phys. Rev. C 27, 2742 (1983).
15. R. Shypit et al., Phys. Lett. B 124,314 (1983).
16. C. Hollas, private communication.
17. J. A. McGill et al., Phys. Lett. 134B, 157 (1983).
18. G. Glass et al., Phys. Lett. 129B, 27 (1983).
19. B. J. VerWest, Phys. Lett. B 83, 161 (1983).
20. J. A. Tjon and E. van Faassen, Phys. Rev. C, to be published.